

What's Up with House Mice? – A Review

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ABSTRACT: The house mouse is probably the most widespread invasive mammalian species, being ubiquitous worldwide. In commensal situations, they are known mainly for property damage, for consumption and contamination of stored foods, as a noise/sanitation/odor nuisance, and as a vector of some diseases. In some field settings, they also cause considerable damage to field crops and to natural resources, such as when introduced to islands. We rely heavily upon sanitation, rodent-proofing, capture devices, and rodenticides to control populations and reduce damage. However, a number of situations exist whereby these traditional methods are not adequate or appropriate: crop damage during "mouse plagues" in Australia, livestock feed consumption and contamination and disease hazards in poultry and animal facilities in the U.S., and natural resource damage on small islands. In this review, challenges and some potential solutions to house mouse management are presented, including genetic resistance to anticoagulants, the effectiveness of baits given abundant food resources, the re-invasion problem and need for perimeter strategies, efforts with fertility control, and the need for effective multi-capture trap devices. In difficult situations, an IPM strategy that incorporates a combination of methods closely integrated with land uses and management practices is necessary.

KEY WORDS: commensal rodents, house mouse, *Mus domesticus*, *Mus musculus*, rodent management, rodenticides

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INTRODUCTION

House mice (*Mus musculus* and *M. domesticus*) are the most widespread mammalian species in the world, next to humans. House mice originated in the grasslands of Central Asia and followed humans around the world. There are a number of species in the genus *Mus*, but most common around the world are *Mus musculus* and *M. domesticus*. Here, we use the term house mouse to refer to both, as there is debate in taxonomic circles as to the distinction between these two very similar species and whether or not they should be lumped under *Mus musculus*. In general, *Mus domesticus* is slightly larger and more uniformly colored (a buff or gray brown) than *M. musculus*. The genus is described in more detail in Lund (1994) and Nowak (1999).

There has not been a review of house mouse biology, behavior, ecology, damage, and management in quite some time. In this review, we revisit these topics. We also point out some of the differences between mice and the commensal rats (*Rattus* spp.). We examine some serious problem areas around the world involving house mice. Finally, we consider some management and research needs that could enhance our management house mice populations and the damage they cause.

ABILITIES AND VALUES OF HOUSE MICE

House mice have remarkable abilities that have allowed them to be highly successful in colonizing most of the world. Perhaps chief among these are their reproductive potential and their adaptability. Several notable researchers have made a career of studying this remarkable species (e.g., Berry 1970, Bronson 1979). This small (± 20 g) and highly prolific animal is a continuous breeder in many situations; a female can produce 6-8 litters, each with 4-7 young, per year. The young mature within 3 weeks or so, and they soon become reproductively active. House mice are short-

lived (generally less than 1 year) and have high population turn-over rates; they are truly an "r-selected" species. In one study, 20 mice placed in an outdoor enclosure with abundant food, water, and cover, became a population of 2,000 in 8 months (Corrigan 2001).

Mice are known to survive and even breed under very extreme conditions, including deep in coal mines, at high mountain elevations, and even in meat cold storage lockers. Although they evolved as grass and seed eaters, mice can feed on virtually anything. They can use almost anything for shelter and bedding. Mice are curious by nature and are very opportunistic, unlike the commensal rats, which are much more neophobic. The abilities of mice to climb, jump, swim, dig, gnaw, and access small places are truly remarkable. Mice have been documented to jump about 46 cm and to get through holes only 6 mm in diameter (Baker *et al.* 1994).

House mice have quite a behavioral repertoire. Over 50 individual behavior elements have been described, including non-social behaviors (such as grooming), social investigation and sexual behaviors, and agonistic behaviors (Mackintosh 1981). In fact, "behavioral flexibility" is considered key to the success of the house mouse as a species. As a result, house mice have complex, yet adjustable social systems.

In general, mice live in extended family units called "demes" (Latham and Mason 2004). The size of the area used by this group can vary greatly, depending upon resource availability and densities, from a few meters to over 100 m on a side. Mice have a strong sense of touch and kinetic abilities that allow them to move rapidly in total darkness and return home after extensive forays (Corrigan 2001). Pheromones play an important role in this ability and also are essential in social interaction and breeding activities. Mice are primarily crepuscular or nocturnal, although this varies by density, resource availability, and predatory pressures. Mice are very

active, perhaps as much as 50% of the time, although much of this is entails grooming (Latham and Mason 2004).

Unlike commensal rats, mice are nibblers, eating small but frequent meals (Timm 1994a, Corrigan 2001). They can eat 10-20% of their body weight per day. As a result, they pass 50 or more fecal pellets per day. The small droppings in infested buildings are a "trade-mark" of their presence, even though they are rarely seen. Unlike rats, mice do not require free water and can meet their water needs through metabolism of solid foods. They will drink free water, however, if it is available.

It is important to distinguish between "traditional" commensal populations of house mice, which live in close association with humans and their habitations, and feral populations that truly live off the land. Feral mice typically have larger home ranges and spend less time in territorial defense and patrolling their territories (Latham and Mason 2004). They tend to be seasonal breeders and exhibit large seasonal fluctuations in densities. They prefer areas of dense ground cover and populations are driven by rainfall and seed fall patterns. House mice do not compete well with the commensal rats nor with established native rodent populations. Hence, feral mouse populations usually occur where this situation does not exist, such as on agricultural lands in Australia and on islands with few or no terrestrial mammals. These situations are discussed in more detail below.

House mice play a number of important ecological roles, such as providing a prey base for a large array of predacious animals cycling nutrients, and dispersing seeds and spores. Also important is the very large role of house mice in medical research. They have been used to this purpose at least since the mid-1660s, and modern laboratory strains were developed in the early 1900s (Lund 1994). A recent article in *USA TODAY* (March 6, 2006, p. 13D) estimated that as many as 25 million mice are used in medical research each year.

DAMAGE CAUSED BY HOUSE MICE

House mice cause many types of damage (Timm 1994a). A major concern is the consumption and contamination of stored foods; it has been estimated that substantial amounts of stored foods are lost each year in this manner (LaVoie *et al.* 1991). Where feral populations of mice occur, they damage many types of crops in the field, especially corn, cereal grains, and legumes. Mice also consume and contaminate large amounts of livestock feed at animal production facilities.

In buildings, a mouse infestation can be a considerable nuisance because of the noise, odors, and droppings. More importantly, they damage insulation and wiring (Hygnstrom 1995). House fires have been caused from the gnawing of electrical wires; likewise, communication systems have been shut down for periods of time, resulting in economic losses.

House mice are susceptible to a large number of disease agents and endoparasites. Consequently, they serve as reservoirs and vectors of disease transmission to humans, pets, and livestock (Gratz 1994). Important among these diseases are leptospirosis, plague, salmonella, lymphocytic choriomeningitis, and toxoplasmosis.

Finally, when introduced to islands, mice can cause significant damage to natural resources, including both flora and fauna. For example, on Gough Island, mice feed on nestling albatross chicks (Cuthbert and Hilton 2004).

MANAGEMENT OF HOUSE MICE POPULATIONS AND DAMAGE

A large number of methods and materials have been developed to help solve house mouse problems. In general, the use of multiple approaches and materials (that is, employing an integrated pest management strategy) is more likely to reduce the problem to a tolerable level. The tools available and their proper use have been reviewed by Prakash (1988), Timm (1994a), and Corrigan (2001). Many technical guides are also available from Cooperative Extension Service offices, private companies, and agricultural and health departments; many of these are available on the Internet. It seems that a major conference on rodent biology, ecology, and management is held somewhere in the world every 5 years or so and a proceedings made available (e.g., Singleton *et al.* 2003). This is an indication of the continual problems rodents cause and the need for ongoing research and adaptive management.

Among the management techniques for house mice, making resources less available to mice is an essential first step. This is accomplished by good sanitation practices and by making buildings rodent proof (Baker *et al.* 1994). Recall, however, that keeping mice out of buildings is a real challenge because of their remarkable abilities. Nonetheless, the success of commensal rats and mice in urban/suburban, industrial, and agricultural settings is largely attributable to the vast harborage that we provide in those areas.

Traps, especially kill traps, have been used for a long time to control unwanted mice. The history of mouse trap development was reviewed by Drummond (2003). Snap traps are very effective but not always practical to use on a large scale. Appropriate baiting and placement is very important for high capture success (Timm 1994a, Corrigan 2001). Live traps are mostly used for rodent research purposes but have become more popular with the public, many of whom are averse to killing pest animals. More recently, multiple-capture live traps have become available (Temme 1980). When mice are taken elsewhere and released, however, they generally do not fare well, or they cause similar problems there. State agencies have begun to more carefully regulate the relocation of animals because of concerns of humaneness and potential disease transmission.

A variety of other methods and materials have been developed and made commercially available for rodent control. These include animal repellents (chemical, auditory, and visual), glue boards, and the use of cats. Timm (2003) reviewed the use of "devices" to reduce animal pest problems and concluded that most were rather ineffective. Glue boards are not very effective with mice (which tend to jump over them or otherwise avoid them), and one could certainly question their humaneness (Corrigan 1998, 2001). Some cats are efficient predators of mice, but the presence of cats will not eliminate the

mouse population; for the most part, they are harvesting the "surplus" of the mouse population (Timm 1994a). Repellents may protect some resources such as seeds (Nolte and Barnett 2000).

Chemical rodenticides are probably the most important material in our toolbox for dealing with rodent problems. A large number are available on the market, but the active ingredients available vary somewhat by country (Jacobs 1994). Most of these rodenticides are formulated as food baits, but some are available as tracking powders and liquid baits. The latter two can be useful in situations (livestock facilities; zoological parks, granaries) where a highly palatable food source is readily available and the rodents won't eat the rodenticide bait.

Rodenticides are often classified as anticoagulants (further broken down into first and second-generation materials) and the acute toxicants (see Timm 1994b). The first-generation anticoagulants (e.g., warfarin, chlorophacinone, diphacinone) are relatively lower in toxicity and require multiple feedings over several days before they are lethal to the mice. The second-generation anticoagulants (e.g., bromadiolone, brodifacoum) are more potent and were developed starting in the early 1970s, when genetic resistance to first-generation anticoagulants began to occur (Frantz and Madigan 1998). Resistance to some of the second-generation anticoagulants has been reported more recently (Misenheimer *et al.* 1994). Anticoagulants are used in relatively low concentrations (0.0025 - 0.005%), and an antidote (vitamin K) exists in case of accidental intoxication of people, pets, or livestock. A relatively new anticoagulant, difethialone, shows much promise against mice and rats (Marshall 1992). Hadler and Buckle (1992) and Jackson and Ashton (1992) reviewed the history and use of anticoagulant rodenticides. The acute toxicants (e.g., zinc phosphide, cholecalciferol, bromethalin) are toxic to most vertebrates and may kill rodents with a single feeding. Two other acute toxicants (strychnine, sodium monofluoroacetate or '1080') have very limited use in the U.S. and are no longer registered for control of house mice, but they are used fairly regularly in some other countries. Lund (1988) reviewed the use of acute rodenticides.

The use of rodenticides is carefully regulated by federal and state agencies to assure proper use and to reduce adverse effects. Concerns with rodenticide use revolve around primary and secondary poisoning hazards, residue bioaccumulation, and environmental persistence (e.g., Kaukeinen *et al.* 2000).

In general, house mice are somewhat less susceptible to rodenticides than are the commensal rats, and female mice are less susceptible than males (Fisher 2005). In a recent study, we found only the second-generation anticoagulants brodifacoum and difethialone and the acute rodenticides bromethalin and zinc phosphide on oats to be effective with wild house mice in 3-day exposure, 2-choice laboratory trials (G. Witmer, unpubl. data). Of course, other rodenticides probably would have been effective with a longer exposure period. On the other hand, all materials tried (includes first-generation anticoagulants, liquid diphacinone, cholecalciferol, and bromadiolone) were effective against wild Norway rats (*Rattus norvegicus*). Only zinc phosphide pellets were

ineffective against the rats (as they were with the mice) because rodents would consume a small, non-lethal dose, become sick relatively quickly, and then not eat any more. This has been termed "bait shyness". To help prevent bait shyness, it is generally recommended that the rodents in the area be pre-baited with similar, but non-zinc phosphide-containing, bait several days before the zinc phosphide bait is applied. Furthermore, it is often recommended that zinc phosphide bait be not used in an area more frequently than once per season. To avoid development of genetic resistance to anticoagulants, it is often recommended that the anticoagulant active ingredient used be rotated periodically. Behavioral resistance to rodenticides has also been noted in some rodent populations. Because the mouse population occupying a specific location may exhibit differences in bait preference, it is often a good idea to try several different types of bait and monitor their effectiveness (O'Connor and Booth 2001).

Bait stations are commonly used with the application of rodenticides. These stations serve many purposes: protection of bait from moisture and dust; provision of a safe, comfortable place for rodents to feed; limitation of access to the bait by non-target animals; more places are made available to safely place bait; spillage is prevented or reduced; and rodent activity can be monitored by the signs left in bait stations or by food removal (Timm 1994a). Many types of bait stations are available on the commercial market or they can be home-made (Timm 1994a, Corrigan 2001). With mice, bait station placement is probably more important than the type of station that is used (Morris and Kaukeinen 1988).

SOME SPECIAL PROBLEM AREAS

Commercial Animal Facilities

Certain facilities prove to have chronic, serious infestations of mice. These include cattle feedlots, dairies, swine and poultry houses, and zoological parks (Rowe 1981, Corrigan 2001). Livestock feed and grain supply stores may also have chronic problems, although usually not as severe. In these situations, there is virtually always abundant food, water, and shelter available, and conditions are rather constant throughout the year. Sanitation and rodent-proofing are used, but they are very difficult to maintain at high levels. There are almost always other animals present (i.e., livestock, zoo animals) and these "non-targets" make traditional rodent control methods (traps, toxicants) very difficult to apply. Additionally, the facilities are regulated by state and/or federal agencies and inspected for conditions and practices used. This causes anxiety on the part of operators, who will try almost anything to solve the rodent problem or at least reduce it to "acceptable" levels.

Managing rodent problems at these facilities requires constant effort and a certain amount of ingenuity; special care must be taken to not put the livestock or zoo animals at risk (Corrigan 2001). Design considerations and construction materials selected before the facilities are built (or when renovated) can go a long way toward improving the situation (Rosenthal and Xanten 1996). Operators are often perplexed and frustrated when they follow all the guidelines in Extension Service publications on rodent

control at livestock facilities, but still have an obvious rodent problem. Using heavy-duty bait stations is important. The occasional rotation of rodenticide baits is also important to avoid bait shyness or genetic resistance (discussed in detail below). Extreme care must be taken before using bait blocks or packets, because rodents can move these around and the baits may, unintentionally, become available to non-target animals. In some cases, it may be safer and more effective to use tracking powders and liquid baits.

House Mouse Outbreaks or "Plagues"

In various parts of the world, periodic outbreaks, often called "plagues", occur in house mouse populations. The classic example is in Australia, but they have been documented in Hawaii, where increases in the incidence of leptospirosis often follow (Tomich 1986). Outbreaks have also been reported in the continental U.S.; during an outbreak in California in the 1920s, house mouse densities rose to an estimated 200,000 per ha (Nowak 1999).

These outbreaks are most severe and most regular in the agricultural landscapes of Australia. They have been studied extensively, and pro-active management strategies have been developed (e.g., Singleton and Brown 1999). The outbreaks are closely associated with the rainfall patterns and subsequent effects on vegetation. Usually a period of drought years is followed by a good rainfall year, resulting in an abundance of lush plant growth. The mice take advantage of this opportunity to greatly increase reproduction and disperse widely into crop fields, causing substantial losses. After crop harvest, the mice readily invade grain storage facilities, causing another round of damage.

Australian researchers have developed a predictive model, based primarily on rainfall, and it is used for pro-active management (Pech *et al.* 1999; Krebs *et al.* 2004). They have extensively studied the mouse populations, including home ranges, refugia, food habits, reproduction, densities, predation pressures, and management options (e.g., Cantrill 1992, Twigg and Kay 1995). They have also studied the efficacy and hazards associated with various toxic baits (Saunders 1986, Caughley *et al.* 1996). Their strategies include mouse population monitoring, management of uncultivated areas (refugia) around the perimeter of crop fields, and relating crop practices and the timing of baiting to the life cycle of the mice (Brown *et al.* 2004, Singleton and Brown 1999). A very useful tool to increase the knowledge of managers and land-owners and to aid in decision making of the management of house mice is the CD-ROM entitled "Mouser" (Brown *et al.* 2003). It contains several informative modules, additional information sources, and is available for a modest cost.

House Mice on Islands

Another serious challenge posed by house mice is when they become established on an island, usually the result of a shipwreck or the landing of infested cargo (Long 2003). Many islands have few if any native terrestrial predators, and seabirds nesting on the ground are at high risk from introduced predacious species

(Atkinson 1985, Burbidge and Morris 2002). The commensal rodents, including house mice, are omnivorous and will readily take advantage of relatively defenseless eggs, chicks, and small adult birds. They also can have significant impacts on native invertebrates, lizards, reptiles, and plants. A large portion of the total island extinctions of native vertebrates has been caused by introduced rodents (Atkinson 1985).

House mice (and other species of introduced rodents) readily adapt to the environment and resources available on islands. Researchers have noted the "island syndrome" in these populations, whereby the rodent population achieves greater and more stable densities, rodents have greater survival rates and body size, are more sedentary, exhibit lower aggressiveness, have lower reproductive output, and exhibit lesser dispersal tendencies (Adler and Levins 1994).

There are many technical and logistical difficulties in managing or eradicating a rodent population once it has become established on an island (Parkes and Murphy 2003). However, there have been at least 20 successful eradications of house mice on islands (Howald *et al.* 2005). These primarily relied on rodenticide baits (most commonly, brodifacoum), used either by broadcast baiting and/or with a grid of bait stations (e.g., Newman 1994). Careful and thorough planning is required, and adequate resources must be available for a successful outcome. Preventing reinvasion can be especially difficult with house mice, which can readily stow away in cargo brought to the island (Burbidge and Morris 2002).

The presence on the island of endangered animal species, a similar native rodent species, or other non-target vertebrates can greatly add to the challenge of planning and conducting an eradication. Mitigation measures are needed in these cases (e.g., NPS 2000, Moro 2002, Howald *et al.* 2005). Mitigation might involve relocation of some vertebrates at risk, captive breeding programs, protecting some areas from the bait drop, and careful timing of the operation. An additional problem is that certain non-targets (e.g., crabs and ants), while not being affected by the rodenticide used, may swamp the bait and make it less available to the target rodents.

Often several species of invasive plants and animals may occur on the island. It is important to thoroughly think out and assess the implications of species interactions before planning and conducting an eradication of one of those invasive species. Otherwise, unexpected and serious consequences can result (e.g., Blackwell *et al.* 2003). For example, the removal of an invasive herbivore has resulted in an increase in some invasive plant species (Bullock *et al.* 2002).

Additionally, eradication of an introduced rodent population can result in shift in predatory pressures of cats or weasels to native birds. In some cases, the introduced rodent population is sustaining a raptor population (native or introduced) during periods of low prey numbers; without the rodents, the raptors would only be present in low numbers or during brief periods of the year. This has been termed hyper-predation (Howald *et al.* 2005). It is noteworthy that the rodenticide used to eradicate introduced rodents has, on occasion, also helped

eradicate an introduced predator such as feral cats through "toxic prey-loading" (Nogales *et al.* 2004).

It is not uncommon to find, after a successful introduced rat eradication, that a seemingly non-existent house mouse population will suddenly irrupt; this happened on Buck Island in the U.S. Virgin Islands (G. Witmer, unpubl. data) and elsewhere (Billing and Hardin 2000). The phenomenon has been called "competitor release." Presumably, the house mouse population had been greatly repressed by the rat population. More careful planning of the rodenticide delivery system may have resulted in both invasive rodent species being eradicated.

SOME MANAGEMENT AND RESEARCH NEEDS

It is clear that because of their size, abilities, and adaptive nature, house mice will continue to exploit situations presented to them and will continue to be a challenge to control in many settings. Although we have a large number of tools to employ when dealing with house mice, the development of new and improved methods and materials is always evolving and adapting to the many difficult situations where existing tools are rather ineffective.

It is especially important to assess each house mouse infestation for its own unique set of conditions, history, and driving forces. We tend to over-generalize rodent situations and expect that the application of the same tools and approaches to be fully successful in resolving the problem. More and more cases are suggesting that this is not a safe assumption to make.

Rodenticide baits will continue to be a mainstay in our toolbox, but it is necessary to assess that the selected agent (active ingredient, formulation) will be adequately effective in a given situation. We should also look for bait shyness or genetic resistance in a specific population when our traditional materials do not seem to be working.

Development of effective lures for house mice would take advantage of their curious nature and could help determine the presence of mice as well as drawing them to traps, baits and bait stations, or multiple capture devices. Conversely, we need to develop effective, yet safe, mouse repellents so that we can better protect packaged foods, cables, and other vulnerable materials.

Research should continue to develop oral delivery systems. Highly palatable, yet selective, materials are needed that can get chemicals such as vaccines and fertility control agents into mice and through their stomach without degradation. An effective chemosterilant in a good oral delivery system is very much needed for rodent management in situations where rodenticide use is seriously constrained or ineffective (e.g., Marsh 1988).

Research on the use of species-specific diseases and endoparasites should continue. While some work has been done in other countries (e.g., Singla *et al.* 2003), little has been done in the U.S. Additionally, there is a potential to deliver fertility control agents through a species-specific viral vector (Chambers *et al.* 1999), but much research will be required to overcome the many technical difficulties with this approach.

House mice will not just go away. They will continue to follow us and adapt to, and take advantage of, the

situations we make available. The challenge to resource and land managers and to researchers is to assure that the damage levels and lost resources will not become more significant over time or that they will, at least, be maintained at tolerable levels.

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